

# INTERIM GUIDELINES FOR WARM MIX ASPHALT



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# **INTERIM GUIDELINES FOR WARM MIX ASPHALT**

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# INTERIM GUIDELINES FOR WARM MIX ASPHALT

## 1 INTRODUCTION

This document presents the guidelines for the production and construction of Warm Mix Asphalt (WMA) pavement. This technology, which is already in use in the USA and a number of European countries and on a trial basis in India as well, has a great potential of full scale use in the country because of its inherent advantages in terms of reduction of green house gas emissions and economy in construction (because of less fuel consumption in construction) as well as elimination of suspected health hazards to construction workers (according to some studies the fumes from hot bituminous mixes is a health hazard). The guidelines would need to be further refined and amended in course of time with experience gained with widespread use of the technology and therefore, this document may be considered as interim guidelines.

The draft document “Interim Guidelines for Warm Mix Asphalt” was first outlined by Prof. P.S. Kandhal and thereafter brought into shape by Dr. Sunil Bose, Co-Convenor, Flexible Pavement Committee (H-2). Ms. Ambika Behl, Scientist, CRRI also assisted in the preparation of the draft document with her valuable inputs and vast field knowledge. The Committee deliberated on the draft document in a series of meetings. The H-2 Committee finally, approved the draft document in its meeting held on 21<sup>st</sup> December, 2013 and authorized the Convenor, H-2 Committee to send the final draft for placing before the HSS Committee. The Highways Specifications & Standards Committee (HSS) approved the draft document in its meeting held on 7<sup>th</sup> January, 2014. The Executive Committee in its meeting held on 9<sup>th</sup> January, 2014 approved the same document for placing it before the Council. The Council in its 201<sup>st</sup> meeting held at Guwahati, Assam on 19<sup>th</sup> January, 2014 approved the draft “Interim Guidelines for Warm Mix Asphalt” for publishing.

The Composition of H-2 Committee is as given below:

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## **2 SCOPE**

### **2.1** The Guidelines describe:

- i) A range of warm mix technologies, which have potential for use in bituminous construction like Dense Bituminous Macadam (DBM), Bituminous Concrete (BC) meeting the quality and performance requirements of IRC:111 and Recycled Asphalt Pavements (RAP).
- ii) The essential requirements of collaborative effort between the technology provider/the product supplier on the one hand and the contracting agency on the other with a view to promoting the use of the warm mix technology.

**2.2** Since the Warm Mix Asphalt technology uses a variety of patented products as additives, which come in different forms such as solid, liquid and powder and use different processes for administering the additives and mixing, these guidelines do not prescribe any specific product or process except in a generic manner at the level of technology.

**2.3** The guidelines further recommend that the contracting authorities may accept any technology that claims to meet the requirements of these guidelines provided such a claim is (a) substantiated by laboratory and field tests, and (b) backed by a collaboration between the contracting agency and the product/technology provider in a manner that ensures joint and several responsibility.

## **3 OVERVIEW OF WARM MIX ASPHALT TECHNOLOGY**

**3.1** The basic principle of this technology is that by adding certain additives at the final stages of the mix production, the coating of the aggregates by the binder is greatly enhanced and can be achieved at a considerably less temperature (typically 30°C less) compared to the hot mix process wherein bitumen is heated to a sufficiently high temperature to make it fluid enough to surround the aggregates and coat their surfaces. In hot mix process, it is viscosity of bitumen alone, which is less at higher temperature, that plays the main role in coating of aggregates. In warm mix technology, this can be achieved in three different ways, viz. by increasing the volume of bitumen, by making the bitumen less viscous, by reducing the surface tension at aggregate bitumen interface etc.



**3.2** Currently there are more than 30 different WMA technologies, using patented processes and products, which have capabilities of bringing reduction in mixing, laydown and compaction temperatures of bituminous mixes in one of three different ways as described above. These guidelines covers currently adopted Warm Mix Asphalt technologies globally, classifying them into four main categories. Currently there are altogether more than 30 different WMA technologies. Although the end effect of reduction of mixing, laydown and compaction temperatures are the same, the different technologies work in different ways. The additives, which are either waxes or other hydrocarbon modifiers improve lubrication by reducing the viscosity of bitumen and allow a reduction of 28°C to 40°C in mixing and compaction temperature. Typical dosage amounts are 0.5 to 1.5 percent by weight of bitumen. Sometimes these additives are also added as modifiers for increasing the stiffness of asphalt mixes, for specialty applications, such as in racing tracks.

### **Waterbased Technologies**

#### **1) Foaming**

In essence, the “water technologies” use fine water droplets to expand the volume of binder in the mix by causing it to foam. This has the effect of increasing the volume of the bitumen, enabling it to coat aggregate at lower temperatures. The foaming technology can be further subdivided into two classes, foaming additives and water injection system. The foaming process works by creating foamed asphalt that improves coating and compaction at lower temperature. Water expands 1,600 times when converted into steam at atmospheric pressure, and the steam is encapsulated by viscous bitumen producing foam, which occupies a much greater volume compared to the original bitumen. The water for creating the foam is either added as water through a water injections stem in a specialized equipment, or from zeolites (which contain about 20 percent water). Water is added at a rate of 1.25 to 2.0 percent by weight of bitumen (about 500 ml of water per ton of mix), whereas the zeolites are added a rate of 0.1 to 0.3 percent by weight of the mix. Foaming by water allows 18°C to 30°C reduction in temperature whereas foaming by zeolites allows a reduction of 30°C to 40°C.

##### **i) Water carrying chemical additives**

Natural and synthetic zeolites are mineral additives used to introduce water into the mix thereby creating “in-situ” foaming within the bitumen.

Zeolites in general are added to the mix with the filler during mixing process. As the mixing temperature increases the zeolites slowly release their absorbed water into the bitumen, which is dispersed throughout the mixture in the form of very fine foam droplets. This causes an increase in the volume of the bitumen and leading to improvement in its ability to coat the aggregate.

##### **ii) Wet fine aggregate addition systems**

In this process the bituminous binder is added to the heated coarse aggregate in the mixer. Once the coarse aggregate are well coated, fine aggregate at ambient temperature with moisture content of around 3 percent is introduced. The moisture vaporizes, causing the binder coating the coarse aggregate to foam, which in turn encapsulates the fine aggregate.

## 2 Chemical Additives

WMA technologies utilize chemical additives that have little effect on rheological properties of the binder. These products may be supplied in pellet, powder or liquid form, and then mixed into the binder or directly added to the mix. Chemical additives are Surfactants (surface active agents) that reduce surface tension between the polar aggregates and non-polar bitumen, improve wetting and reduces internal friction, and allows a reduction of 28-50°C in mixing and compaction temperatures. Typically they are added at the rate of 0.20 to 0.75 percent by weight of bitumen.

## 3 Rheological Modifiers

The wax based products can be described as viscosity modifying organic additives that reduce binder viscosity at high temperatures and thus allow lower mixing and paving temperatures.

## 4 Hybrid Technologies

Hybrid technologies utilize a combination of two or more WMA technologies to achieve the reduction in temperature. For example, Low Energy Asphalt (LEA) utilizes a chemical additive with a water injection system to improve coating at lower temperatures.

## 5 Other Technologies

Finally, there are products that were originally developed for other uses, but do incorporate the WMA technology for reducing temperature and hence better utilization of the product. Examples are (sulfur and WMA) and TLAX (Trinidad lake asphalt and WMA technology).

The additives come in different forms, such as liquid, powder, pellet and are administered in the mix production process at different stage. Accordingly, some modification in the bituminous mixing plants is necessary to administer the controlled dosage of the additives. Some additives in liquid form can be pre-blended with bitumen and would need no modification in the conventional mixing plant provided the blended bitumen contains the right dose of additive. Other additives, which are administered in the mix at certain stage during the mix production process, would require some modification in the conventional mixing plants. These modifications would generally require a separate material (additive) feed system and a material metering system (to ensure the right dosage) which should be integrated with computerized plant control system of the mixing plant. The water-based WMA technologies would additionally need a water injection system as well.

Apart from such plant modification as required to administer the additives (described above), some modification need would arise out of the need to operate the plant at reduced temperature compared to that for the conventional hot mix production, for example recalibrating the fuel burner, aggregate drying system, bitumen heating system as also to take care of the possible consequences of lower temperature operation, such as contamination of the mix by un-burnt fuel and trapped moisture, condensation of bag house fines, etc.

## 4 BENEFITS OF WARM WARM MIX ASPHALT

- i) *Environmental Benefits:* The single most important justification for use of this technology is that it reduces the emission of green house gases by



around 25 to 30 percent and controls thereby global warming. This would earn tradable carbon credit. Secondly, the technology is quite compatible with Reclaimed Asphalt Pavement technology, which saves the requirement of fresh aggregates and reduces the environmental hazard associated with dumping of damaged pavement materials.

- ii) *Health Benefits:* The fumes from hot mix asphalt are known to be potential health hazards, especially for the construction workers. Reduced temperature of the mix avoids this health hazard.
- iii) *Technical advantages:*
  - a) Lower mixing temperature reduces the oxidation and ageing of bitumen and thereby gives longer lasting pavement by delaying fatigue cracking.
  - b) Much improved workability of the mix at lower temperatures gives better compactibility and larger compaction window.
  - c) Reduced rate of cooling of the mix (due to low initial temperature of the mix) permits longer haul distance from the plant to work sites and better cold weather construction opportunities.
- iv) *Cost benefits:* WMA is most likely to have long term cost advantages, though its estimation should be case specific. The cost advantage is a trade-off between the additional cost of using the additives and technologies (including plant modification) and cost savings achieved through reduced fuel consumption, longer life of pavement and use of recycled material.

## 5 CHOICE OF AN APPROPRIATE WARM MIX ASPHALT TECHNOLOGY

In the Section dealing with 'overview', the principles behind various alternative technologies and different additives have been presented. These provide the general guideline for an appropriate choice of technology. Secondly, since the plants and equipment used for producing WMA mixes would remain essentially the same (at least till such time the technology proliferates and its use becomes widespread) as that for HMA mix, it would be necessary to ascertain the nature and feasibility as well as commitment to these modifications/changes. Thirdly, the suppliers of the products to be used in works should be willing to take responsibility along with the main contractor not only for their products but for the entire technological solution.

All technologies and all commercial additives should be allowed to compete for acceptance on a work if the following conditions are satisfied:

- Technology and/or product suppliers provide evidence of :
  - a) achieving the reduction of at least 30°C in mixing and laying temperature on some actual work done in the past. The evidence should be in the form of a certificate from the owner/owner's representative of the said work,

- b) additives proposed to be used not having any harmful effects on human health and environment. This evidence should be in the form of test certificates from reputed laboratory,
- c) complete understanding of the technological solution such as dosage of additives, the process of administering the additives in a controlled manner (weight, volume, pressure, temperature, etc.), adequacy of the plant and equipment proposed to be used on the work and if not, the modifications required, quality assurance in the process, etc. This evidence should be in the form of a written quality statement.
- The main contractor provides evidence of understanding of the technological requirement, including modifications in the plant and equipment and acceptance of these requirements. This evidence should be in the form of a written joint commitment statement.

The selection of the best WMA technology depends on many factors, and in most cases is dependent on the monetary incentives and benefits of using WMA. Important factors to consider include the reduction in temperature that is desired, the tonnage of mix that is anticipated and whether or not to invest in plant technology that are needed for certain additives. It should also be pointed out that the “green” benefits of adopting WMA technologies should not be overlooked, and that a reduction in emission through a reduction of temperature can help contractors/agencies receive significant amount of “carbon credits.”

## **6 DESIGN OF WARM MIX ASPHALT MIXES**

The quality and performance of the mix shall be the same as specified for HMA in IRC:111 except for mixing and laying temperatures, which should be at least 30°C less than those specified for HMA. The threshold of 30°C is considered technologically feasible as well as desirable from the point of view of fuel savings of some significance.

Design of mix, quality of inputs (except the additives) and tests required to be performed shall follow the same procedures as specified in IRC:111. In addition, the following WMA specific tests shall also be performed:

- Coating
- Compactibility
- Moisture Sensitivity

The above parameters should be verified first in the laboratory, after the criteria are satisfied, a field trial of at least 500 m length shall be constructed, and the parameters obtained in the laboratory may be verified.

### **6.1 Aggregate Coating**

- WMA sample shall be prepared as per AASHTO T195 (Refer **Annex 1**) at a temperature at least 30°C lower than conventional hot-mix.
- The warm-mix shall be evaluated for coating as per AASHTO T195.
- Minimum 95 percent of the coarse aggregate particles shall be fully coated at a temperature at least 30°C lower than conventional hot-mix.



## 6.2 Compactibility

Since the mixing and compaction temperature of the warm-mix samples are lowered by at least 30°C compared to the conventional hot-mix, it is important for the warm-mix samples to attain specified mix densities at adopted lower temperatures. In order to verify that the warm-mix samples attain sufficient density at least 30°C lower temperatures relative to the conventional hot-mix, the following is proposed:

- Three hot-mix specimens shall be prepared conforming to the Job Mix Formula (JMF) as per AASHTO T245 (also adopted in MORTH Section 500 Table 10). (Refer **Annexure 1**)
- Similarly, three more warm-mix specimens shall be prepared conforming to the JMF. In all cases the JMF shall be made in the same procedure as per conventional mixes except at a temperature at least 30°C lower than the hot-mix samples as per AASHTO T245. The compactive effort should be similar for both mixes. In case there is a specific change required by an additive manufacturer to suit the JMF requirements the same shall be permitted except that the Specified Properties in the Guidelines shall have to be adhered to.
- The bulk specific gravity ( $G_{mb}$ ) of all the specimens shall be determined as per AASHTO T166.
- The theoretical maximum specific gravity ( $G_{mm}$ ) of the bituminous mixture of HMA and WMA shall be determined as per AASHTO T209.
- The air voids of both the mixes shall be determined as per the following equation:

$$V_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100$$

- The ratio of the air voids shall be as per the following equation:

$$R_{va} = \frac{V_a \text{ of WMA}}{V_a \text{ of HMA}}$$

- The ratio shall be such that  $0.9 < R < 1.1$

## 6.3 Moisture Susceptibility

Warm-mixes are typically prepared at least 30°C lower temperatures, it is likely that the aggregate can retain some residual moisture, especially when the aggregate are porous and when the moisture content in the aggregate is high due to recent rains. It is recommended that the warm-mix additives or processes should also behave as anti-stripping agents, and should be able to improve the resistance of the mix to moisture susceptibility even when produced at temperatures at least 30°C lower than conventional mixes. If the warm-mix additives cannot perform as an anti-stripping agent, it must be mandated to add either hydrated lime or a liquid anti-stripping agent to the mix to improve resistance to moisture damage. However in case of WMA using foaming technology use of anti-stripping agent or lime may be detrimental.

- Six samples of the compacted HMA mix conforming to the JMF as per AASHTO T245 (Refer **Annex 1**) shall be prepared in the first instance.

- The specimens shall have  $7.0 \pm 0.5$  percent air voids.
- Six samples of warm-mix specimens conforming to the JMF shall be prepared at a temperature at least  $30^{\circ}\text{C}$  lower than the hot-mix samples as per AASHTO T245. The compactive effort shall be similar for both mixes, and the specimens shall have  $7.0 \pm 0.5$  percent air voids.
- The Tensile Strength Ratio (TSR) of the hot-mix and the warm-mix shall be determined as per AASHTO T283. The TSR value of HMA shall meet the requirement of minimum 80 percent as specified in IRC:111. A TSR of above 80 percent for the warm-mix that is prepared at least  $30^{\circ}\text{C}$  below corresponding hot-mix will ensure sufficient resistance against moisture susceptibility.

## 7 PRODUCTION OF WARM MIX ASPHALT

### 7.1 Mixing Plant Requirements

WMA requires mix temperatures to be significantly reduced. The two basic types of bituminous mixing plant most commonly used are the batch type mixing plant and the continuous drum type plant, both of which types can be adapted to manufacture WMA.

For production of warm mixes that also contain reclaimed bituminous mixes, mixing plant design should include adequate features. When any of the various types of mixing plants are used, it should be ensured that the Recycled Asphalt (RA) and the virgin aggregates are properly blended together; the blending process shall facilitate proper heat transfer and shall prevent both physical and thermal segregation.

As with any new technology, there are a few concerns about the production of WMA, specifically because of the lower temperatures that are utilized during production. Fortunately, all of these problems are expected and solvable, in many cases through the adoption of techniques that could also be utilized for improving conventional HMA production.

The first concern is about incomplete drying of aggregates (specifically the internal moisture) at the reduced temperatures. It has been seen that for aggregates with an absorption value of less than 1 percent, drying of aggregate has not been reported to be a problem at WMA temperatures. To prevent the incomplete drying of aggregates, it is suggested that stockpiles be kept as dry as possible by sloping sides, paving surrounding areas, and keeping them under cover. To dry aggregates with high moisture content the retention time in the dryer drum could be increased and the dryer shell should be insulated properly. Ways to detect incomplete drying include a greater than  $20^{\circ}\text{C}$  fall in temperature in mix between discharge and loading, dripping water from silos and excessive steam from slat conveyors and a loss of more than 0.5 percent of the weight of mix during moisture content test.

The second concern is regarding incomplete combustion of fuel at the reduced temperature and the resulting risk of getting unburnt fuel in the mix.

Evidence of such a problem include brownish color of mix and higher than normal emissions. Proper maintenance and tuning of burner, and preheating of burner fuel are recommended



solutions to this problem. The last but not least problem is the potential of condensation of baghouse fines, leading to the clogging and decreased efficiency of the emission control system.

Recommended solutions include proper preheating of baghouse, sealing of leaks, adjusting flights and slopes of the dryer to increase baghouse exhaust temperature, insulation of baghouse and ductwork and addition of duct heaters to increase baghouse temperatures, if needed. A high i.e. within the range of 0.28 to 0.35 kg/cm<sup>2</sup>. A high-pressure drop within a range greater than 0.28 to 0.35 kg/cm<sup>2</sup> across the bags is an indicator of caking due to condensation.

## 7.2 Warm Mix Asphalt Technology Addition Systems

For WMA Technologies, both rheological modifier and chemical additive types that are blended into the binder shall be added through the mixing plant's normal binder addition system. These may also be blended at terminals and supplied to project sites through conventional transportation system.

Water carrying chemical additives, which are in powdered form, can be added manually into the pugmill of batch type mixers either through the filler system, or by intruding it through the RA collar.

Equipment to produce foamed bitumen may be installed on both batch and continuous drum mixing plant types. The systems obviously operate differently, with separate generations of foamed bitumen for each batch in the former type of plant and a continuous production of foam in the latter plant type's case.

Conventional types of bituminous mix plants shall have the following monitoring and control systems:

- Binder storage tank heating temperature
- Integrated individual cold feed hopper (new aggregate and RA) and burner fuel flow
- Burner fuel flow meter
- Infrared temperature monitor
- Infrared silo discharge temperature monitor

Foaming systems should include integrated flow metering and pressure sensing systems for both the binder and the water used to produce the foam.

## 8 CONSTRUCTION OPERATION

The construction operation for WMA shall same as that prescribed for HMA and shall be in accordance with the IRC:111 except that the mixing, laying and rolling temperature for WMA shall be as indicated in **Table 1**.

**Table 1 Mixing, Laying and Rolling Temperatures for WMA\***

<b>Bitumen Grade</b>	<b>Mix Temperature (°C)</b>	<b>Laying Temperature (°C)</b>	<b>Rolling Temperature (°C)</b>
VG-40	135 max	120 min	100 min
VG-30	130 max	115 min	90 min
VG-20	125 max	115 min	80 min
VG-10	120 max	110 min	80 min
Modified Bitumen**	135 M max	120 min	100 min

\* In case of special conditions including but not limited to long hauls, cold paving conditions, etc. the recommendations of the WMA technology supplier shall be followed.

\*\* The properties of modified binder shall conform to IRC:SP:53.

## **9 QUALITY ASSURANCE**

The extent and level of quality control of Warm Mix Asphalt shall be same as that of HMA and specified in IRC:111. In addition, one test each for coating, compactibility, moisture susceptibility shall be carried out for each mix design. Further, when the WMA mixes include reclaimed bituminous mixes, additional testing shall be required.

The properties of the binder contained in the RA have to be taken into account at mix design stage and the consistency of the recovered binder properties shall be checked regularly.

Typically the moisture content, grading and binder content of each RA fraction shall be checked prior to the start of the day's mix production.

## **10 COLLABORATIVE EFFORTS BY CONTRACTING AGENCY, TECHNOLOGY PROVIDER AND THE CONTRACTING AUTHORITY**

**10.1** WMA technology will actually be applied in works by the Contracting agency. While the quality and performance of the work is the responsibility of the Contracting agency, the product technology provider has to take responsibility for the efficacy of the product and the technology. It is essential, therefore, that both contractor and the product/technology provider come to an understanding or agreement with regard to their respective roles and formalize them in the form of Joint Venture or Contractor-Subcontractor or Contractor-Supplier arrangements, delineating therein their respective roles, committing themselves to joint and several responsibilities, and accepting these arrangements to be made a part of the contract for work to the extent it involves WMA work.

**10.2** The product/technology provider should give reasonably detailed information in narrative form supported by sketches, diagrams, process flow charts, laboratory and field test evidences, etc., with regard to but not limited to the following:

- i) The trade name of the product and the form in which available (such as liquid, powder, pellet, etc.)
- ii) Technology description (such as water-based, rheological modifier, surfactants, etc.)

- a) Recommended dosage and target reduction in mixing and laying temperature
- b) The additive feed system (such as pre-blended with binder, water injection system, separate feed system)
- c) The stage of mix production process at which the additive is to be administered (such as with hot binder before mixing, hot aggregate before mixing, pug mill during mixing)
- d) The additive metering system (volumetric, gravimetric, temperature, pressure, etc.)
- e) The controls required (manual, centralized computer control or parallel computer control for additive feed system) for administering the recommended dosage
- f) Whether the mixing plant to be used on the work has these systems and controls or not, and if not, the modifications required in the plant
- g) Safety and precautions in material (i.e. the additives) storage, handling and processing

**10.3** The contracting agency should undertake to procure the materials, bring out modifications required in the plant and equipment as required specifically for administering the additives in a controlled and safe manner and also for the general requirement of operating the mixing plant at reduced temperature. The general requirements would be but not limited to

- i) Tuning the burners (to prevent un-burnt fuel getting mixed with warm mix)
- ii) Modifying dryer flight configuration (to ensure proper drying of aggregates)
- iii) Modifying dryer drum inclination (to ensure proper drying of aggregates)
- iv) Preventing condensation of bag house fines (to ensure efficiency of emission system)
- v) Preventing un-burnt fuel and moisture getting mixed with the warm mix produced
- vi) Maintaining computer control of plant operation and not allowing any overriding manual control
- vii) Doing a trial run of plant operation
- viii) Doing a test section of suitable length

## **11 ROAD MAP FOR WARM MIX ASPHALT TECHNOLOGY**

It is necessary that every user of the technology monitors and evaluates the performance of the WMA technology, creates a database in a standard format and uploads it on its website to make it accessible to any interested party. Over time the success stories will lead to the wide spread use of the technology, lessons can be learnt from not so successful ones and the unsuitable ones would fall by the way side.



## Annexure 1

(Refer Clause 6)

### Properties of WMA to be Verified Based in Accordance with Testing Procedure as per AASHTO/ASTM Standards

- i) Coating - (AASHTO T195/ASTM D2489)
- ii) Compactibility - (AASHTO T245/ASTM D1559)
- iii) Moisture Sensitivity - (AASHTO T283/ASTM D1075)

#### AASHTO T195/ASTM D2489

The standard method of test for “Determining degree of particle coating of Asphalt Mixture”, helps in determining the particle coating in asphalt mix based on the percentage of fully coated aggregate present in a mix. The specification also helps in determining the mixing time required for satisfactory coating of aggregate in the asphalt mixture.

After producing WMA mix by lowering the temperature by at least 30°C lower than conventional hot-mix, samples of the mix are taken immediately after discharge from the pug mill. Coating is only measured on aggregate retained on 9.5 mm sieve. So the material is sieved on a 9.5 mm sieve while still hot and roughly 200-500 gram of sieved sample is collected.

The percentage of coated particles is determined by

$$\% \text{ Coating} = \frac{\text{No. of completely coated particles}}{\text{Total No. particles}} \times 100$$

At least 95 percent of the coarse aggregate particles shall be fully coated at a temperature at least 30°C lower than conventional hot-mix.

#### AASHTO T245/ASTM D1559

The standard method of test for “Resistance to plastic flow for bituminous mixture using Marshall Apparatus” covers the measurement of resistance to plastic flow of cylindrical bituminous mixture samples by the means of a Marshall Apparatus.

This test method is specified to verify that the warm-mix samples attain equivalent resistance to plastic deformation relative to conventional mixes at temperatures at least 30°C lower than conventional hot-mix. The specification details the procedure for preparing a cylindrical bituminous mixture sample of 100 mm diameter consisting of around 1200 g of material. The sample is prepared by compacting using a standard Marshall Hammer. The samples are checked for Marshall Stability and flow under a constant displacement rate testing using a Marshall Apparatus after being immersed in water at  $60 \pm 1^\circ\text{C}$  for 30 to 40 minutes.

WMA mixes shall have at least 9kN Marshall Stability value (12 kN if sample prepared with PMB) and flow between 3 to 6 mm.

**AASHTO T283/ASTM D1075**

The standard method for “Resistance of compacted asphalt mixture samples to moisture-induced damage” covers preparation of specimens and the measurement of the change of diametrical tensile strength resulting from the effects of water saturation and accelerated water conditioning, with a freeze-thaw cycle, of compacted asphalt mixtures. The results may be used to predict long-term stripping susceptibility of the asphalt mixtures and evaluate liquid anti-stripping additives that are added to the asphalt binder.

The test is performed by compacting cylindrical bituminous mixture specimens to an air void level of six to eight percentages. Three specimens are selected as a control and tested without moisture conditioning, and three specimens are selected to be conditioned by saturating with water undergoing a freeze cycle ( $-18^{\circ}\text{C}$  for at least 16 hours), and subsequently having  $60 \pm 1^{\circ}\text{C}$  water soaking cycle for 24 hours. The specimens are then transferred to a  $25 \pm 1^{\circ}\text{C}$  water bath for two hours and then tested for indirect tensile strength by loading the specimens at a constant rate and measuring the peak force required to break the specimen. The tensile strength of the conditioned specimens is compared to the control specimens to determine the Tensile Strength Ratio (TSR).

$$\% \text{ TSR} = \frac{\text{Tensile strength of conditioned samples}}{\text{Tensile strength of unconditioned samples}} \times 100$$

The Tensile Strength Ratio (TSR) of the hot-mix and the warm-mix shall be determined as per the AASHTO T283. A TSR of above 80 percent for the warm-mix that is prepared at least  $30^{\circ}\text{C}$  below corresponding hot-mix will ensure sufficient resistance against moisture susceptibility.

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**(The Official amendments to this document would be published by the IRC in its periodical, 'Indian Highways' which shall be considered as effective and as part of the code/guidelines/manual, etc. from the date specified therein)**